Informing Material Specification

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INTRODUCTION

Architecture is entering a radical rethinking of its material practice. Advancements in material science and more complex models of material simulation as well as the interfaces between design and fabrication are fundamentally changing the way we conceive and design our built environment. This new technological platform allows an unprecedented control over the material. Creating direct links between the space of design and the space of fabrication, the idea of the hyper specified material developed in direct response to defined design criteria calls upon a new material practice in which designers of artifacts are also designers of materials. In this practice materials are seen as *bespoke composites*, differentiated and graded, and whose particular detailing is a central part of a projects overall solution.

The development of this new material practice is central to emergence of a new more *sensitive* approach to design. As we enter an era of design thinking that seeks to respond to the increasing social, environmental and sustainable demands of building practice we need to develop new models by which we can realize our architecture. To engage directly with material design and to partake in the development of new material systems is to be part of an inventive culture of material engineering. From the very small to the very large, the imagination of *performative materials* that are created in response to highly defined design criteria are challenging the traditional boundaries of design and representation. Performative materials can be *structurally differentiated* designed in response to a variegated load, *materially graded* responding to change in program or property or *computationally steered* incorporating actuated materials designed for state change and environmental response. Hyper specified and designed, what they have in common is that they are developed in response to particular criteria by which the strength, structure, elasticity or density of a material can be devised.

This paper will present a dual investigation into material design as an architectural practice. Taking point of departure in two cross disciplinary workshop investigations, we explore ways in which materially embedded sensing can lead to the making of new strategies for material design. Both investigations use textiles as a model for material thinking. Developing bespoke interfaces between programmable architectural design tools and advanced computer numerically controlled (CNC) knitting machines we understand the practice of textile design as a particular class of material design that enables variegation across both material and structure. Our aim for the experiments is firstly: *the design of active materials* that use integrated sensing as a means for triggering actuation and secondly: *the design of graded materials* that use integrated sensing as a means for specification. In the following we will discuss how these two practices can be interlinked, what are the shared concepts and technologies and can these be advantageously merged.

Key words: Architecture, textiles, material design, embedded sensing, parametric design, digital fabrication.

A NEW DESIGN PARADIGM: THE EMERGENCE OF EMBEDDED SENSING

The emergence of a new performance-based architecture is radically changing the ways in which information is used in architecture. If buildings used to be based on static information as program, structural requirements and regulations these are today accompanied by sources of dynamic information. The new practices of performance based design employ environmental data, energy calculations, material and structural simulation, human behavior and perception, as input parameters interfaced directly with design intent. But how is this idea of the performative informed? What is the data that we are designing from and how can the idea of localized information help inform these emergent practices?

The development of new sensor based systems in the fields of robotics, pervasive and ubiquitous computing has led to the proliferation of the use of sensors in the built environment. The idea of integrating sensing into buildings, to trigger actuation of electronically steered systems such as lighting, heating, ventilation or air conditioning, have become commonplace and as these technologies mature we are encountering ever more sophisticated ways of understanding how self-sensing and self-regulating can inform the built environment. As described by Cecil Balmond architecture is giving to new practices in which sensing plays an integral part:

> "Today architecture is moving away from static compositions of inert building materials, towards dynamic interactive arrays of components and their interfaces, controlled by sensors, controlling devices and other feedback mechanisms integrated into the structures. These immersive environments can anticipate and adjust themselves to emergent pattern of their use and inhabitation."[1]

The desire to integrate sensing into the built environment has led to the imagination of smart composites in which the sensing component is embedded directly into the material of the architectural membrane. Here, the differentiation between building - as an object of control - and sensor - as a means of control - is replaced by performative hybrid materials that amalgamate multiple material properties, both active and passive, into one engineered composite.

Early research-based example for the exploration of these systems is demonstrated in Kieran Timberlake's Smart Wrap project from 2002.[2] Here, a thin plastic film is used as a substrate to integrate light sensors that trigger printed organic light-emitting diodes that in turn find their energy through printed organic photovoltaics. However, in this project the film remains essentially separate from the actual material of the façade, creating a building system that is a based on the idea of paneling and a material system that is founded on the principle of flat layering. Recently, a series of cross disciplinary projects from the fields of architecture, design and interaction design examining the ability to merge material and computation has led to an inquiry into 'transitive materials' that combine material performance with steered performance.[3] In projects such as Pulp-Based Computing[4] and Xeromax Skin,[5] both based on paper or Personalized Furniture[6] and ProtoDeck,[7] both based on wood, electronic circuitry as well as the sensing and actuation of the system is laid into the material system. In these examples the material design includes the computational and the steered with traditional material crafting allowing actuated performance to become a conversation between the two material systems. At different scale and with much higher degree of material diversity and composition, Philip Beesley is investigating a similar trajectory of material thinking. In his installations, such as Hylozoic Ground and Sargasso Cloud, he develops highly complex material systems in which passive and active materials are joined.[8]

Looking beyond architecture and design to the field of engineering the practice of embedding sensing has been further expanded. Here, a more materially led inquiry in which sensors are directly integrated into the material systems so as to monitor performance and facilitate maintenance. The placing of wireless sensors for example into cast concrete structures such as highways and bridges that track the electrical potential, resistance, moisture and temperature of the material allow for real-time tracking of structural performance.[9] In this way the environmental impact, the corrosion of the steel reinforcement and the wear that extreme temperature changes poses can be understood and evaluated. Examples from other material domains such as steel works[10] and fiber reinforced composites[11] demonstrate similar emerging design practices. Rather than using the sensor data in a direct feedback loop triggering actuation the aim here is to survey the building, gathering information across its life time and performance.

Our aim is to understand the interconnections between these different emerging practices. If both practices are informed by the ability to design materials that are capable of sensing their environment, how can we as designers interface and make use of this new situated and materially specific information? If we can collect information, whether internal or external, material, structural or performative including temperature, light, humidity and human presence; this data is in constant flux making it difficult to extract the significant information. By recording, storing and collecting it we gain knowledge about the immediate environment in which the building is embedded. How can we create feedback loops between design intent and material sensing and what are the ways in which this information can be meaningfully employed? The potential of this information to directly inform the design process and the implications of this ability to influence the process of fabrication is of key interest in this paper.

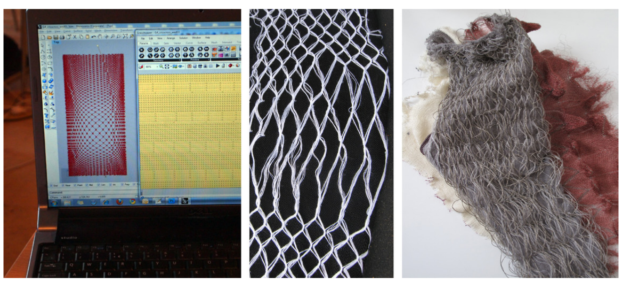

Figure 1. examples showing the interconnections between the diagram, embedding sensing and material specification.

TOWARDS ENVIRONMENTALLY INFORMED MATERIAL SPECIFICATION

In our investigation the aim for material sensing is to inform material design. By creating direct feedback between material sensing and material design, our aim is to develop informed design criteria for hyper-specified, materially and structurally variegated materials developed in direct response to their site and use. The projects use textiles as a model for material thinking. Textiles are an interesting model for complex material composition as they fundamentally are defined as systems of assembly. The structures of weaving, knitting and pleating, are systems by which single fibers are composed to create unified materials, and as such they are open for further re-composition. When looking to the field of textile design the idea of merging computationally steered materials with traditional materials in complex composites has strong precedence in the Smart Textiles field. During the last 20 years there has been a proliferation of sensor integrated fabrics used in a variety of application such as bio-medicine, safety and military.[12] The creation of conductive and resistive fibers has allowed the design of soft circuitries that are directly integrated into the actual fabric. Here, conductive paths simply replace or compound existing material structures. Early precursors of this kind of material thinking can be found as early as 1960 in Edgar Ross's woven circuit board in which woven wire is used to create flexible circuits,[13] and projects such as Animated Quilt[14] and Dynamic Double Weave[15] further explore this trajectory of thinking.

The investigations build on former research into material specification in textile based structures. The ability to highly control the distribution and specification of material fabrication allowed us to strategically incorporate and situate sensing as part of the design. Sensing devices were used to record human interaction which produced accumulative numerical information over time. This paper reports on the use sensing data as a direct trigger for actuation as well as its application as an input for design. Variegated input parameters reflect the rhythms and intensities of use, illustrating the changes in the environment of a building over time. Using advanced parametric design environments this data can be harvested and informed back into the design diagram infusing it in real-time with intensities directly corresponding to contextual conditions. In this way we were able to expand our thinking of material specification to incorporate environmental data as design feedback.

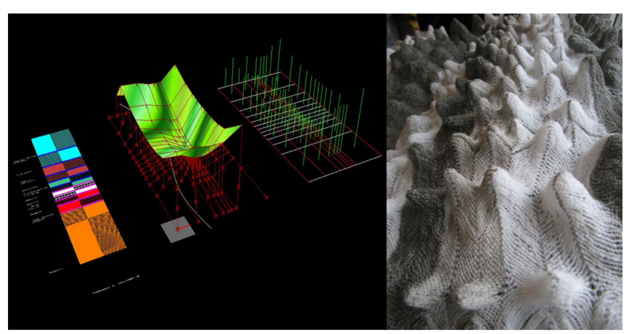

Figure 2. feedback parameters as the basis for creating design iterations

THE TWO WORKSHOPS: SHENKAR AND SMARTGEOMETRY 2011

The paper reports on two separate workshops, both of which were held as one-week cross disciplinary workshops for architects, textile designers, practitioners, researchers and students. Both workshops were based on our own development of bespoke interfaces that link between standard architectural design environments (Rhino and Grasshopper), CNC knitting machine (Stoll) and simple computational steering (Arduino microprocessors). We initially devised this interface for the fabrication of the architectural research probe Listener; a prototype design project exploring textile design as a model for material specification in architecture.[16]

In the two workshops we expanded this method to include a series of new design patterns and matured the interfaces between design and fabrication. The workshops also expanded the material investigation adding a wider variety of fibers allowing more material differentiation and a larger span of behaviors. Whereas the first workshop centered on the design integration of interaction and responsiveness into the textile membranes, the second focused on the implementation of feedback to inform material specification.

WORKSHOP 1: DESIGNING FOR ACTUATION

The first international workshop entitled "Architectural Knitted Surfaces –Computational/ Electronic" was held at Shenkar College of Engineering and Design, Tel Aviv. The workshop invited participants from architecture, textiles, interior design, and interaction design to work together in cross disciplinary teams developing performative textiles. The design teams were asked to generate ideas of interior membranes that could react to user behavior. By integrating conductive and resistive fibers directly into the knitted surface, the textiles collapse sensing and actuation creating hybrid surfaces that are both materially designed as well as computationally steered. The workshop asked how modes of interaction can be variegated. Rather than presenting the user with an even surface of engagement, the investigation asks how interactive responsiveness can be tuned so that it is more or less sensitive in respect to its spatial position, use or occupation.

The designed textiles embody this computational variegation as a material differentiation. Each of the designs is based on an existing textile structure. The structures are modified creating a non-repetitive pattern. Using standard architectural design environments we developed a design process in which the structural properties of the textiles were diagramed allowing direct design control of the surface. The diagrams are parametrically defined and steered by attractor lines that can be interactively changed by the design teams. The attractor lines repel and contract the distribution of points gradually across the surface.

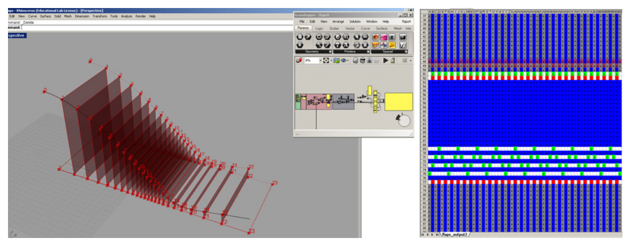

Figure 3. A diagram across platforms: in CAD environment and excel visualization

The importance of the diagram is that it acts as an interface to the CNC knitting machine. Owing to the initial interface we developed in the Listener project the interactive manipulation and adjustment of the attractor lines directly results in an automatic regeneration of the machine code. The diagrams are in this way the foundation for the material specification and determine the material patterning. Furthermore this differentiation is also structural. The tension and number of knitted loops in the textile structure is defined in the diagram. Loops may be loosely or closely constructed determining behavioral attributes such as elasticity and rigidness.

In the workshop this design process enabled an iterative testing of different material compositions for a range of new variation. We were able to fabricate quick prototypes with different material specifications and computational behavior. The integration of either conductive yarn as soft switches[17] or standard sensor devices such as light resistors and piezo-electric flex sensors, involved "breaking down" the integrated knitted circuitry into differentiated sensing areas. Each of the areas functioned as an independent trigger activating local response through LED lights, electroluminescent (EL) wire or vibration motors.

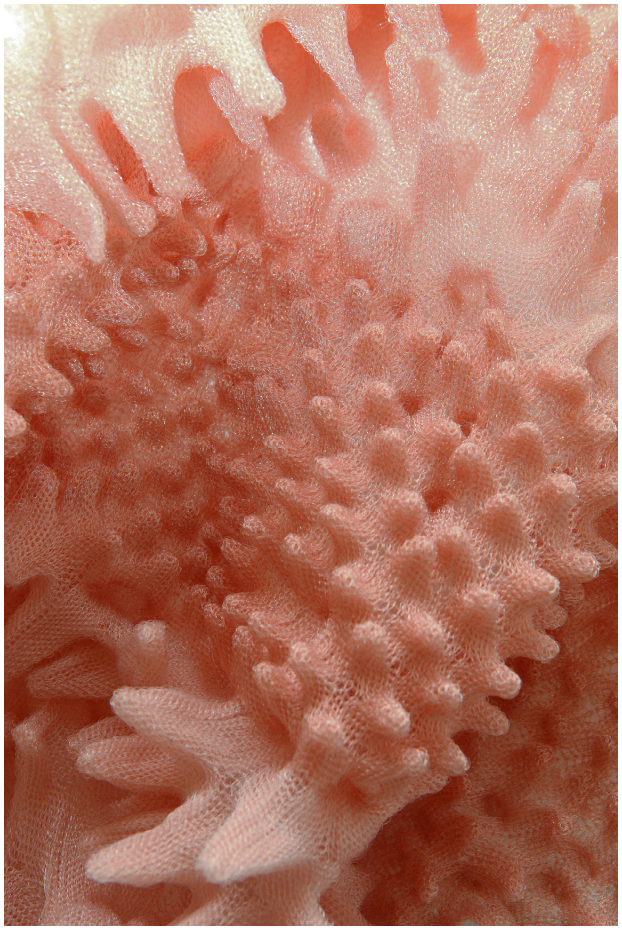

Figure 4. non repetitive pattern becomes an interface for interaction

WORKSHOP 2: DESIGNING FOR MATERIAL SPECIFICATION

The second workshop, "Performing Skins", took place as part of SmartGeometry 2011 "Informing Digital Design with Real World Data" in Copenhagen. In this workshop our aim was to find new ways of defining material specification. If the first workshop used parametric design tools for deforming the initial textiles structures, this second workshop aimed to define material compositions in direct response to accumulated local information harvested by integrated sensors.

The design teams were asked to imagine the textile membranes as building skins detailed in response to environmental impacts. With a focus on humidity, we asked participants to design membranes that act and react upon the presence of water. Whereas in the first workshop a variety of sensors were used, this time conductive wire was used as an interface for capacitance sensing.

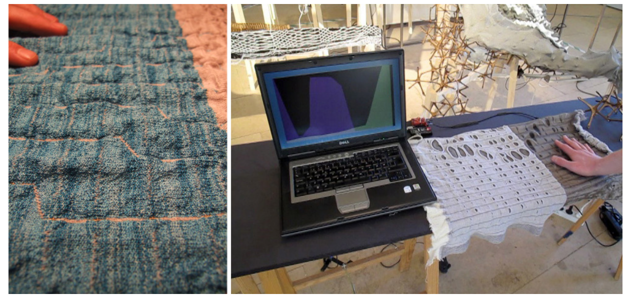

Figure 5. conductive wire as an interface for capacitance sensing

As in the first workshop we developed initial diagrams by which the material variegation in the knitted surfaces were defined. The diagrams allowed the specification of structural as well as material changes and the strategic inlay of sensor bands in the form of knitted-in conductive yarns. Through an iterative design process a first generation of material designs were used to gather local sensing data. This sense data was then interfaced with the parametric diagrams allowing a direct feedback loop between design and fabrication. Using simple architectural parametric tools (Firefly and Grasshopper) the sensors provided a stream of numerical readings reflecting the fluctuation in humidity. The analogue signals were converted into digital signals using an Arduino microcontroller, and values were amplified into relevant output parameters for the design diagram.

The harvested data was fed back into the new active diagrams changing them in real-time with response to the contextual conditions of the surface, producing differentiated geometrical definitions for the production of new iterations. In this way we were able to expand our thinking of material specification to incorporate environmental data as design feedback.

CONCLUSION

This paper reports on two interlinked design processes: that of integrating sensor-actuator systems to create *robotic membranes*,[18] embedding sensing and actuation directly into the material properties of architecture, and the practice of integrating sensors to create membranes that are *active readers*, producing data and informing material specification. Both processes use textile as a model for thinking how new material practices challenge architectural design. Both workshops produce working prototypes linking advanced computational interfaces to the digital fabrication processes. These prototypes function both as conceptual models and as physical artifacts of hyper specified materials.

The question is therefore: in what way are these two design processes connected and how could we integrate them advantageously? If the ability to integrate sensing and actuation allows materials to become interface system capable of communicating between designers, users, the building and the environment, then a new set of considerations come into play. On the one hand we need new interfaces by which to interpret sense data and implement the gathered knowledge in meaningful ways. An important factor becomes the new temporality of this design process. Information is gathered in time, accumulated as data scapes that here appear. The embedding of sensors into the fabric of architecture allow our building to speak back to us. As reflected upon the in the current exhibition *Talk to Me: Design and the Communication between People and Objects* at the Modern Museum of Art in Manhattan, curator Paola Antonelli writes:

> "All objects occupy a unique position in material culture, and all of them contain information beyond their immediate use or appearance. It is not enough for designers today to balance form and function, and it is also not enough simply to ascribe meaning. Design now must imagine all its previous tasks in a dynamic, animated context… Things may communicate with people, but designers write the initial script that lets us develop and improvise the dialogue."[19]

On the other hand these design processes also challenge the way in which we understand the solidity of our built environment. Rather than thinking the design process as being finished when the building is completed, the integration of sensing and its feedback to fabrication allow us to consider the building lifecycles in which components or skins are continually re-fabricated. Much like a snake shedding its skin, perhaps buildings in the future will accumulate knowledge about their surroundings and allow for the regeneration of their material presence over time. This would further expand a sensitive approach to design, where social, environmental and sustainable conditions as well as human interaction are embedded into the material production.

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